Table 5.7 Cessna 414 data, July 10, 1997

Run Number	Nominal Altitude*	Leg (See map)	DPC	Serving Cell Antenna System	Avg Pwr dBm (10kHz) Hpol ant	Avg Pwr dBm (10kHz)	Avg Pwr dBm Grayson
10R	5,000	WARE to WAR	ON	Omni	-121.3	-127.6	-132.2
10S	5,000	WAR to WARE	ON	Omni	-120.8	-127.0	-132.2
10T	5,000	WARE to WAR	ON	Smart	-127.0	-128.0	-131.2
10U	5,000	WAR to WARE	ON	Smart	-125.3	-127.8	-129.0

**Subject to weather/ATC induced changes as noted in logs appended to 1997 report*

(The levels shown in Table 5.3 through Table 5.7 reference the output of the antenna system at the site. That is, power has been adjusted to the value it would read at the output of the 1 5/8" coaxial cable entering the shelter.)

(For 10kHz resolution bandwidth, the thermal noise floor is -134dBm. The noise figure calculated for the Madill test setup is 4.2dB, so the measurement noise floor is about -129.8dBm. For 20kHz BW, the measurement noise floor rises to -126.8dBm, and for 30 kHz, it is -125.0dBm.)

These tables tell much of the story from the 1997 test.. Note that the high altitude runs (15,000 feet and above) observed with the spectrum analyzers had average recorded amplitudes less than 2dB above the measurement noise floor. To disturb the noise floor by 2dB, an interfering signal would have to be approximately 2.3dB *below* the measurement noise floor.

This low received AirCell signal strength is reasonable, considering the observer site is crosspolarized and that aircraft transmitter power averaged 4.5mW when the omni serving cell antenna was in use, and only 0.5mW when smart antennas were used.

The low altitude runs at Madill with dynamic power control 'on' were similar. The average received power recorded was within 2.4 dB of the measurement noise floor, so the average received power from the AirCell call was *still below the noise floor.* This isn't terribly surprising, as aircraft transmitter power averaged about 2.5mW with an omni serving cell, and 0.34mW using smart antennas at the serving cell.

The low altitude runs at Waurika (10R through 10U), collected on the vertically polarized antenna, produced an average level within 3dB of the measurement noise floor, indicating the AirCell call averaged a received power *at or below the measurement system noise floor.*

The only runs to produce average power readings significantly above the noise floor were the circular paths flown around Madill on July 11, 1997 (not shown). These runs (11A through 11D) were made with the aircraft transmit power set to maximum (approximately 70mW) and held there. Dynamic power control, central to AirCell's interference reduction strategy, was disabled. These runs were useful in determining average path loss vs. distance, and crosspolarization isolation. These runs are also useful in comparing the responses of measurement equipment. Runs 11A through 11D *were not* representative of normal AirCell operations. They are mentioned here in the interest of completeness only. Data from runs 11A through 11D is not used herein.

The Grayson data is used for statistical analysis herein in the form of received signal strength probability density functions. The full data set is described in detail in the 1997 flight test report, and the data itself was released on CD to all the participants. The data utilized is grouped into four categories:

- Low altitude, omnidirectional AirCell serving site.
  - Runs 10O and 10P
- Low altitude, smart antenna system at AirCell serving site.
  - Runs 10M and 10N
- High altitude, omnidirectional AirCell serving site.
  - Runs 10G through 10L
- High Altitude, smart antenna system at AirCell serving site.
  - Runs 10B through 10F

5.2 BER statistics

One of the prime metrics carriers now use in designing and optimizing IS-136 TDMA networks is Bit Error Rate (BER). BER is a direct quality metric for the data stream that the IS-136 ACELP vocoder uses to reproduce human voice. If the voice quality is to be good, then BER must be relatively low… In practice, it's never zero, of course. The system is designed to tolerate some lost information bits. Use of coding allows a small percentage of channel errors to be corrected or individual vocoder frames may be blanked if the errors can't be corrected. In most cases, loss of a single vocoder frame isn't perceptible to a human listener. If BER rises sufficiently and blanking of vocoder frames becomes frequent enough, the degradation will at some point become apparent to a human listener. In extremely high BER situations entire words, sentences, or the call itself can be lost.

The questions considered herein are: Given an AirCell presence, what impact will it have on terrestrial caller BER? Is this impact sufficient to take an otherwise 'good' call (one with 2% BER or better) and push it beyond a 2% BER? If a call is already worse than 2% BER, will an AirCell presence make it noticeably worse? This section examines that impact based on measured data.

To make this assessment, an approach was devised to conduct a controlled experiment based on somewhat probabilistic real-world data. Since this experiment had to utilize a real cell site and real subscriber data, it couldn't be a pure laboratory experiment; *exactly* the same subscriber data could not be taken twice – once as a baseline, and again while an AirCell aircraft flew back and forth over the site for a few days at varying altitudes. Subscriber activity changes subtly from day to day, so conclusions drawn from such an experiment would have been questionable – the AirCell impact would have been lost in the other uncontrolled variables.

Thus, it was decided to perform a mathematical assessment based on a combination of 'laboratory data', and field measurements.

In Section 3, the BER response of an actual Nortel cell site multicoupler and radio receiver string was characterized -in detail- in the presence of AMPS interference and noise. Then, the receiver performance was verified as representative by testing two more radios as control samples. The resulting data is the 'laboratory data'… Data taken under calibrated, controlled, reproducible conditions.

The 'laboratory data' provided a mapping for signal, cochannel interference, and noise levels into expected BER. Thus, 'real world' measurements of (second-by-second) subscriber signal strength could be used to calculate the expected Bit Error Rate in the presence of measured 'noise only' or 'noise plus interference' cases taken at Madill during the 1997 AirCell flight tests. The BER impact of an AirCell presence could thus be directly calculated.
The analysis procedure was as follows:

Step 1) Select a BER vs. noise and interference chart from Table 3.3 through Table 3.7. This sets the scenario – Rural, Suburban, etc. as each chart represents operation in a noise floor representative of a particular scenario. An example chart is reproduced below:

Table 5.8 Example BER table

TDMA Carrier (dBm)	OFF	-124	-122	-120	-118	-116	-114	-112	-110	-108	-106	-104	-102	-100	[illegible]	[illegible]
[illegible]																
[illegible]																
[illegible]	X											X				
[illegible]	X										X	X		X		X
[illegible]	X									X	X	X	X	X	X	X
[illegible]	X								X	X	X	X	X	X	X	X
[illegible]	X							X	X	X	X	X	X	X	X	X
[illegible]	X						X	X	X	X	X	X	X	X	X	X
[illegible]	X					X	X	X	X	X	X	X	X	X	X	X
[illegible]	X				X	X	X	X	X	X	X	X	X	X	X	X
[illegible]	X			X	X	X	X	X	X	X	X	X	X	X	X	X
[illegible]	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
[illegible]	X															
[illegible]	X	X	X	X	X	X	X	X	X	X	X		X	X		
[illegible]	X	X	X	X	X	X	X	X	X	X			X			
[illegible]	X	X	X	X	X	X	X	X	X							
[illegible]	X	X	X	X	X	X	X	X								
[illegible]	X	X	X	X	X	X	X									
[illegible]	X	X	X	X	X	X										
[illegible]	X	X	X	X	X											
[illegible]	X	X	X	X												
[illegible]		X	X													
[illegible]		X														

AMPS Interferer (dBm)

Step 2) Select a terrestrial cellular observer site received signal strength histogram. This is a flight test data histogram with AirCell interference present, taken from the 1997 flight test data at Madill. The histogram is chosen from 1 of 4 cases: low/high altitude and omni/smart AirCell server. <u>This histogram is normalized so it is expressed as a probability density function – the sum of the values associated with all possible signal strengths is unity.</u>

Step 3) Perform a dot product of the measured data histogram with a row of the selected BER table (ignoring the interferer OFF column, highlighted in yellow).

For example, in Table 5.8, multiply the probability (from step 2) that the received AirCell interference signal will be –122 dBm by entry 'A' in the green-highlighted row of the table, then multiply 'B' with the probability that the received AirCell interference signal will be –120 dBm, etc., working across the row. Then, sum up all these individual products to form the dot product. (If an entry is 'below' the available data range – for a field to the right of 'M' in the example row, set it to 50% BER in making these calculations. If it is 'above' the available data range, as with the field left of 'A', set it to 0% BER.)

In this example, the result would be the expected value of BER given a TDMA carrier level of –100 dBm (the blue-highlighted table row designation).

Step 4) Repeat step 3 for all rows in the table. The result is a new vector, one in which each entry represents the expected BER corresponding to a specific TDMA signal level, in the presence of the specified measured interference or noise data (from the histogram in step 2).

Step 5) Obtain subscriber reverse link RSL in second-by-second time domain form from the long-term (24 hour) subscriber data. Each reverse link call is extracted and processed separately, discarding periods during which no call was present on the forward channel. The first and last 2 seconds of each call and calls under 10 seconds long were discarded to eliminate failed setups and setup/teardown transients.

Step 6) For each extracted (terrestrial cellular) call, the mean Receive Signal Level (RSL) was determined as an arithmetic average of all measurements taken during the duration of the call.

Step 7) For every measurement of the call's RSL (every 1 second interval), look up two values: the BER expected in the presence of the AirCell signal, using the vector from step 4, and the BER without AMPS interference present, read from the yellow-highlighted column of the BER table (the column labeled "OFF", above. The difference is the BER impact for that second of that call.

Step 8) Accumulate BER and BER impact values for the entire duration of each subscriber call. Aggregate the results for those calls having the same mean RSLs, as determined in step 6.

The results of this analysis are shown in Figure 5.2 through Figure 5.17. These plots contain a mixed presentation of line and bar graph format. The line depicts the BER without an AirCell influence, and the bar graph data indicates the *increase* in average BER when an AirCell signal is present.

The reason for this sort of presentation is that it's important not only to consider the BER impact AirCell operations may have, but what the BER is prior to adding that influence. An additional 1% in BER would be significant if the baseline BER was 2%, because it would push a call from 'good' to only 'acceptable'. On the other hand, an additional 1% BER means far less in operating regions where the BER is already unacceptably high, and a call is seriously degraded in any case. The AirCell contribution must make a perceptible difference to subscribers *before* it can be considered harmful...

Because the AirCell contribution is invisible in many of these plots if the scales are identical, ***note that the AirCell contribution (BER increase) is in some cases multiplied by a factor of 10, 100, or 1000 relative to the baseline BER*** *to make it visible on the chart. The multiplier appears in the legend in the upper right corner of each applicable plot as the magnification factor.*

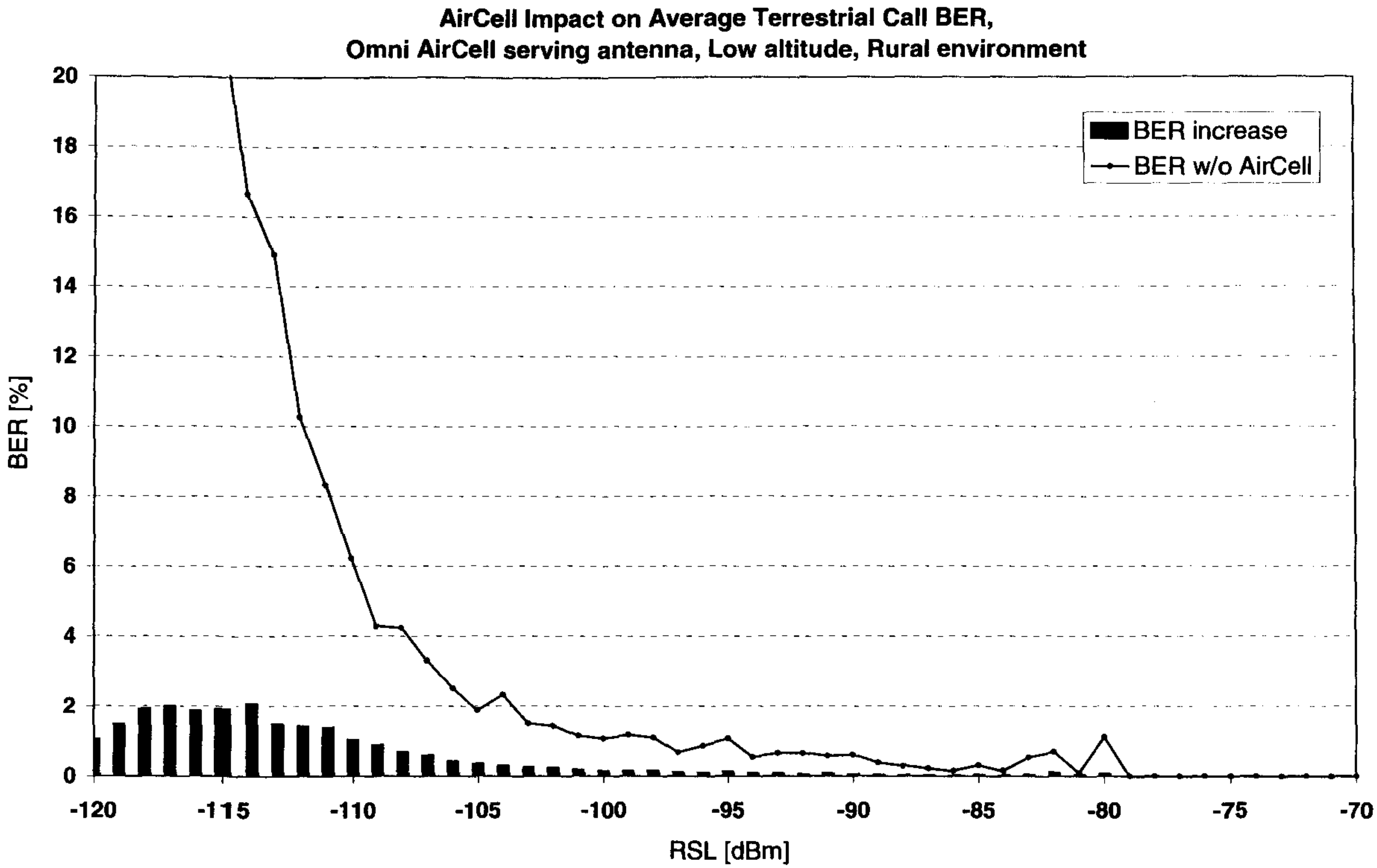

Figure 5.2 BER and AirCell impact, Rural environment, Low altitude, Omni AirCell server

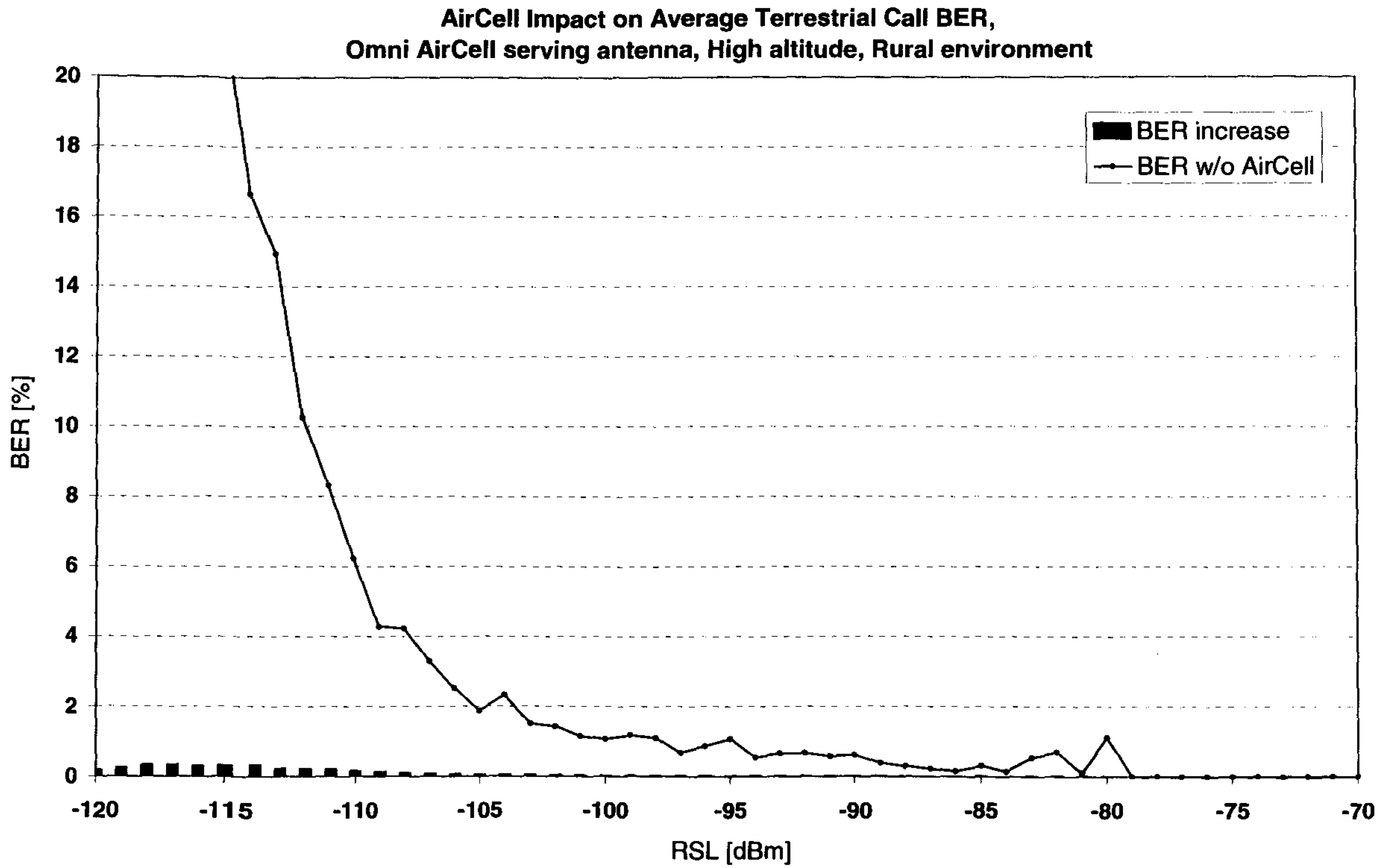

Figure 5.3 BER and AirCell impact, Rural environment, High altitude, Omni AirCell server

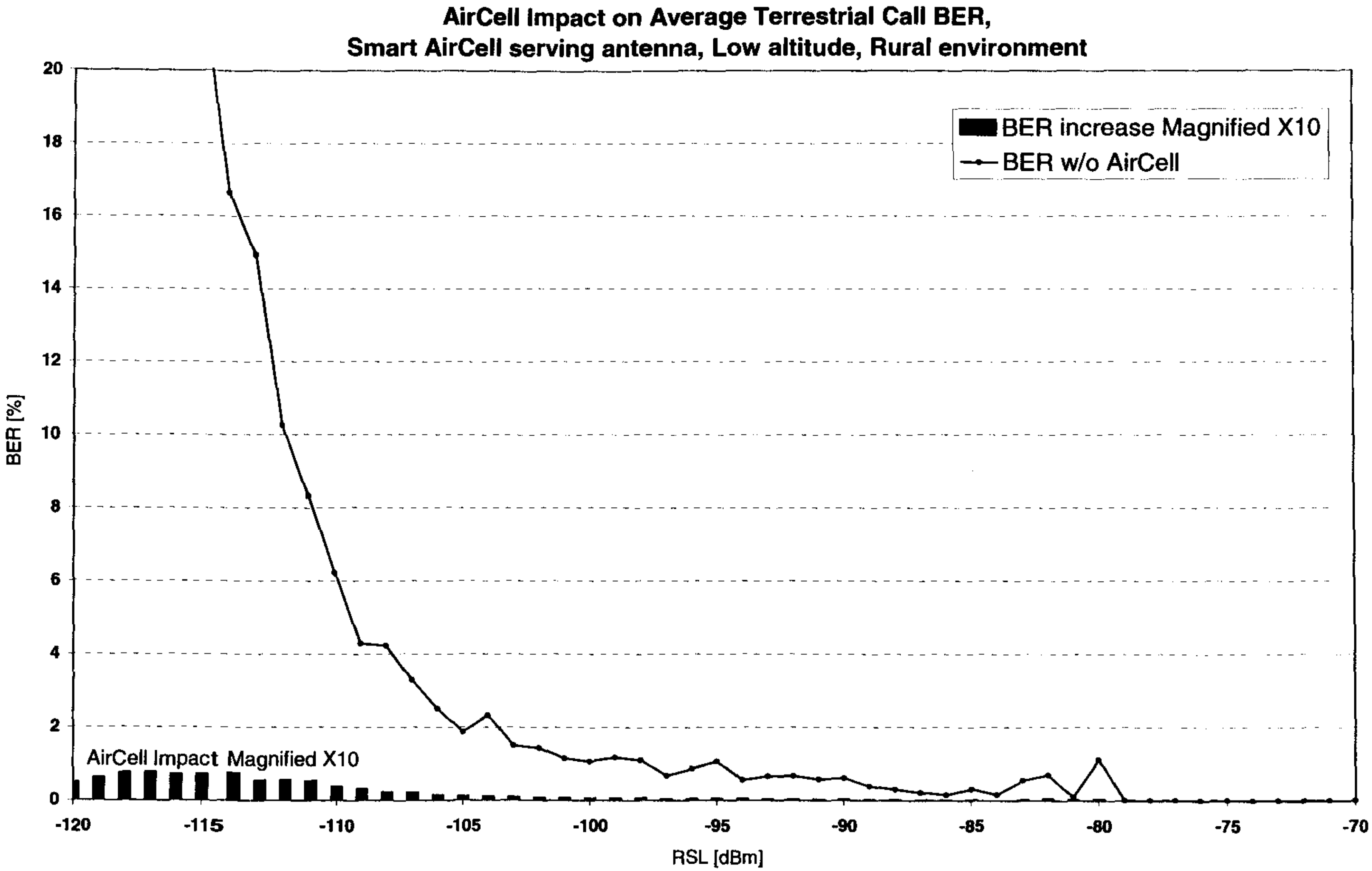

Figure 5.4 BER and AirCell impact, Rural environment, Low altitude, Smart AirCell server

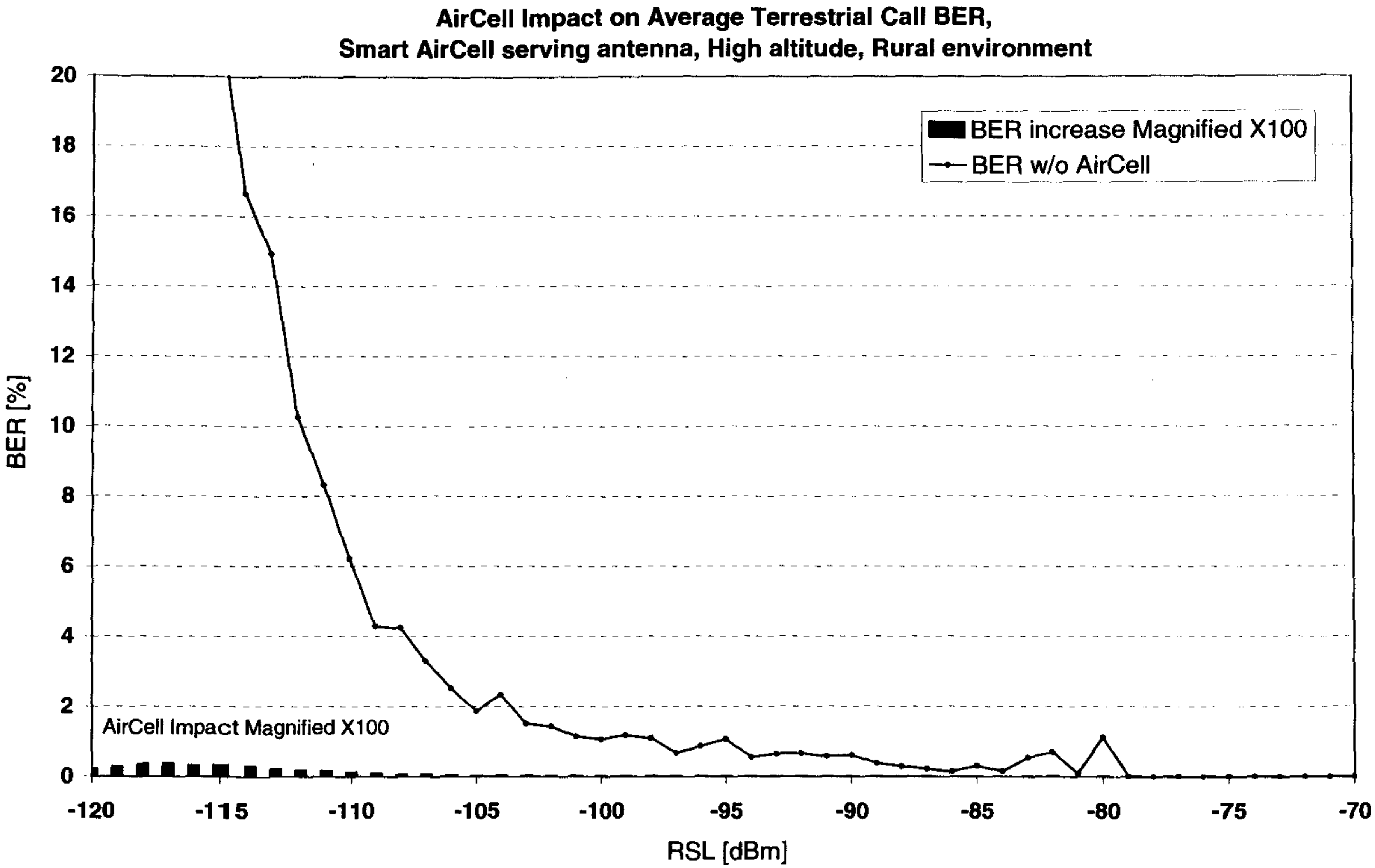

Figure 5.5 BER and AirCell impact, Rural environment, High altitude, Smart AirCell server

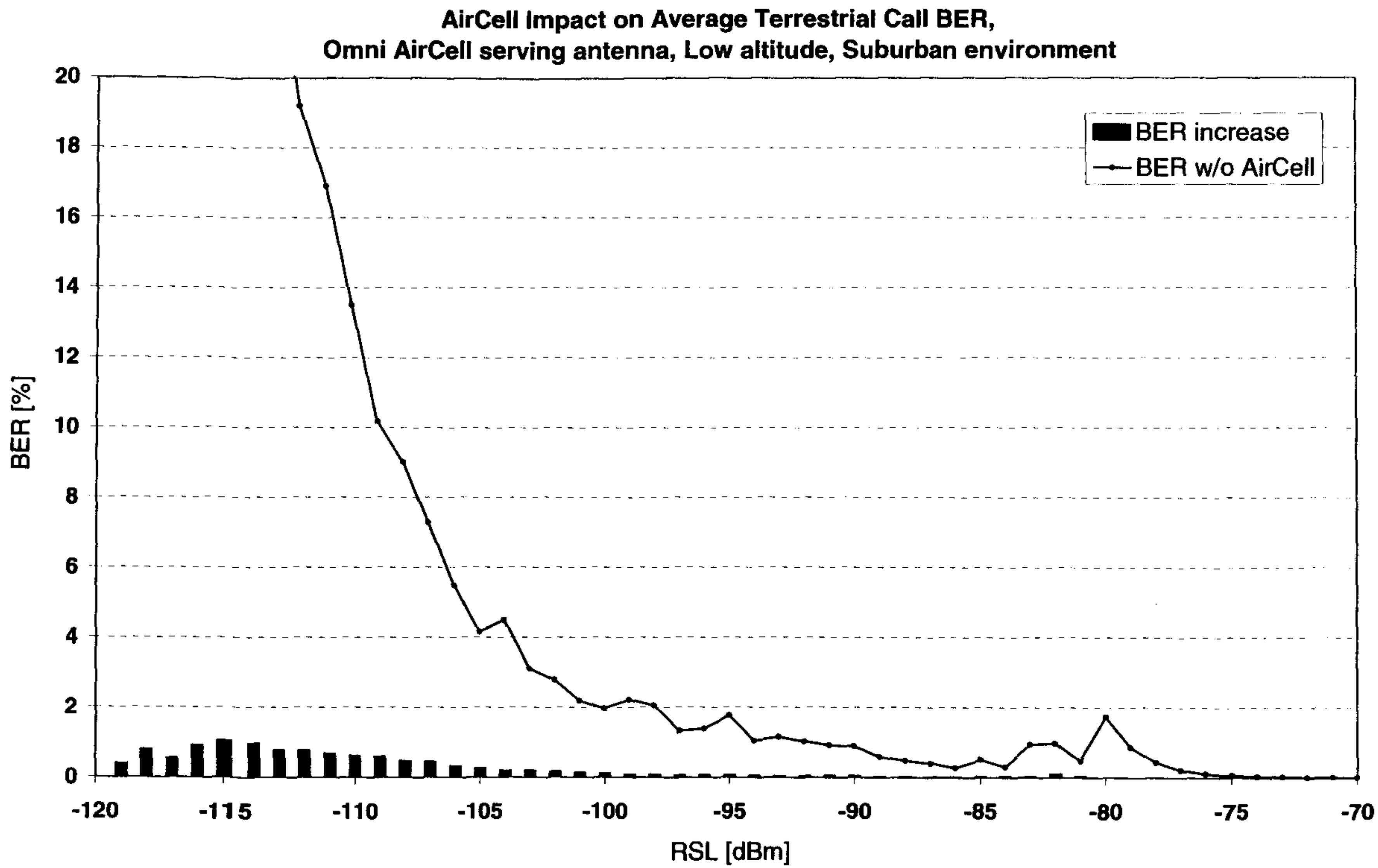

Figure 5.6 BER and AirCell impact, Suburban environment, Low altitude, Omni AirCell server

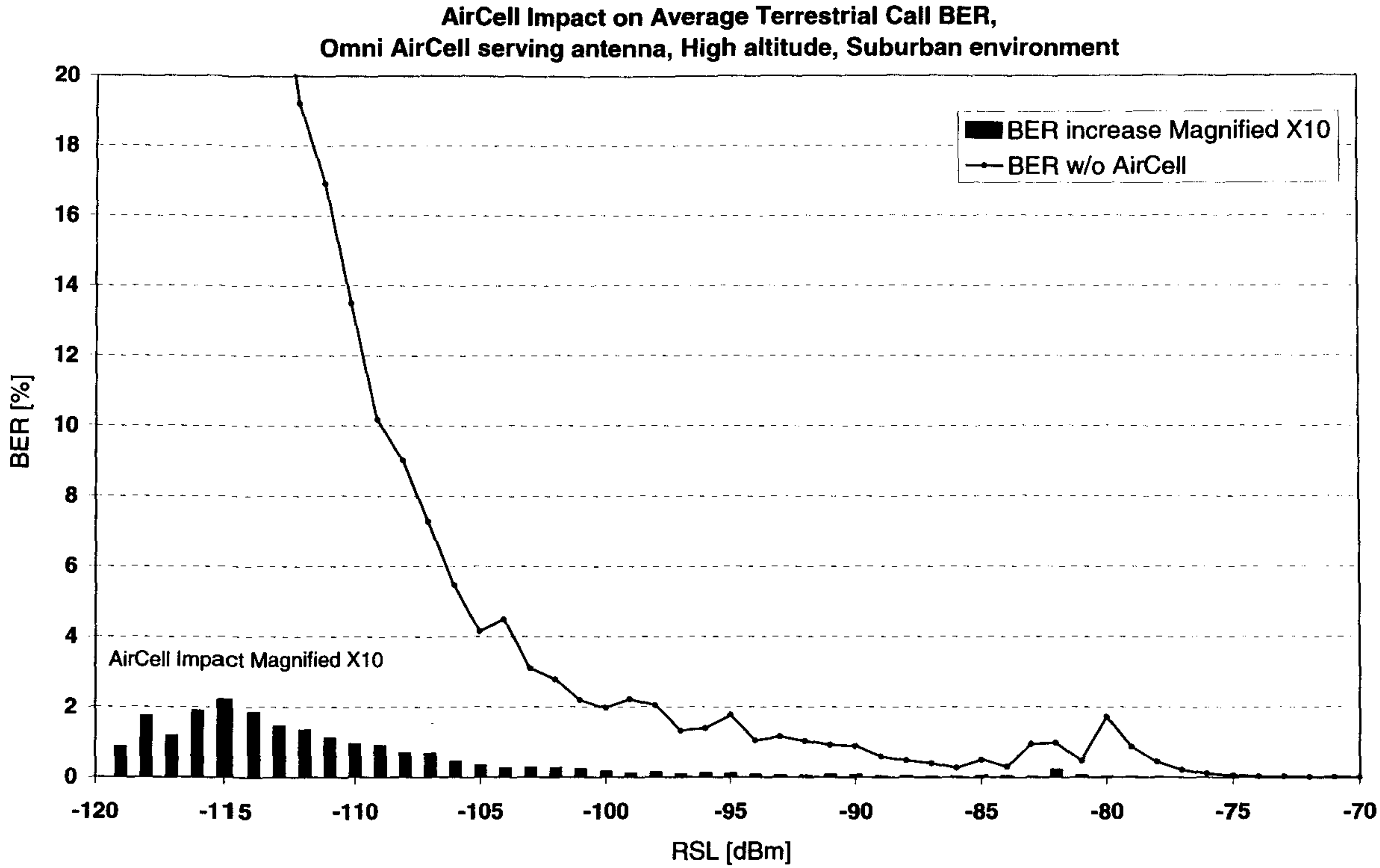

Figure 5.7 BER and AirCell impact, Suburban environment, High altitude, Omni AirCell server

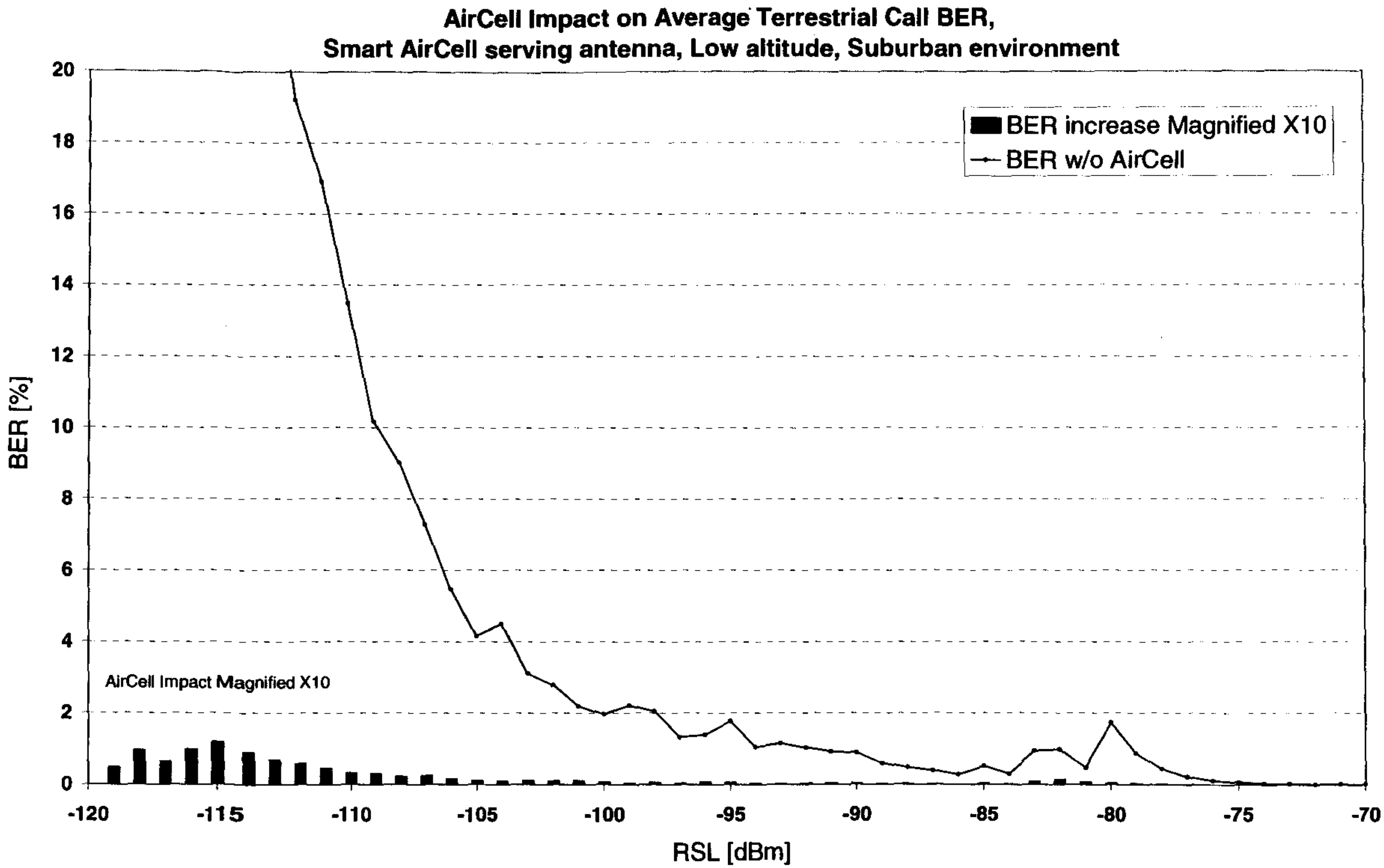

Figure 5.8 BER and AirCell impact, Suburban environment, Low altitude, Smart AirCell server

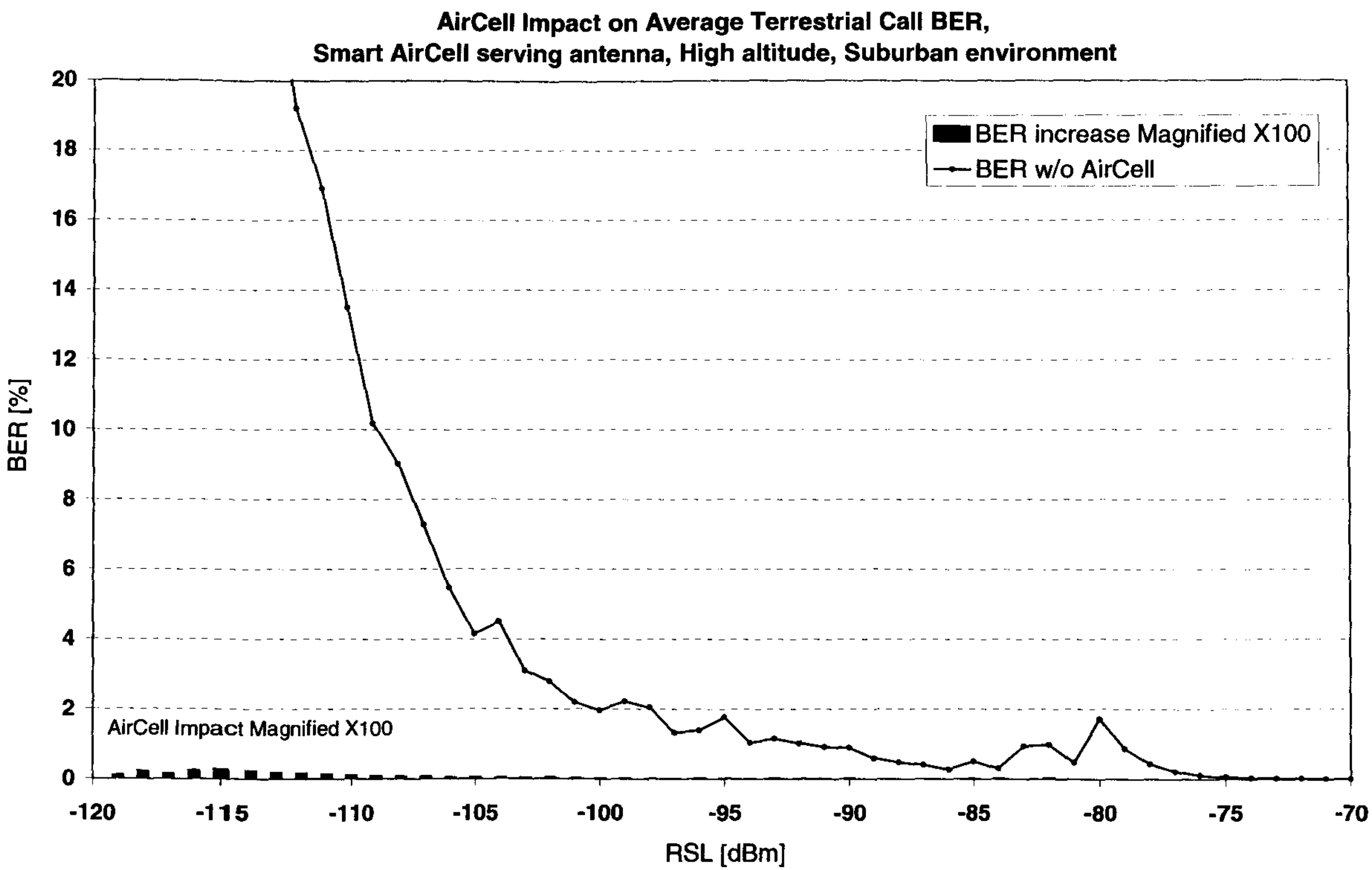

Figure 5.9 BER and AirCell impact, Suburban environment, High altitude, Smart AirCell server

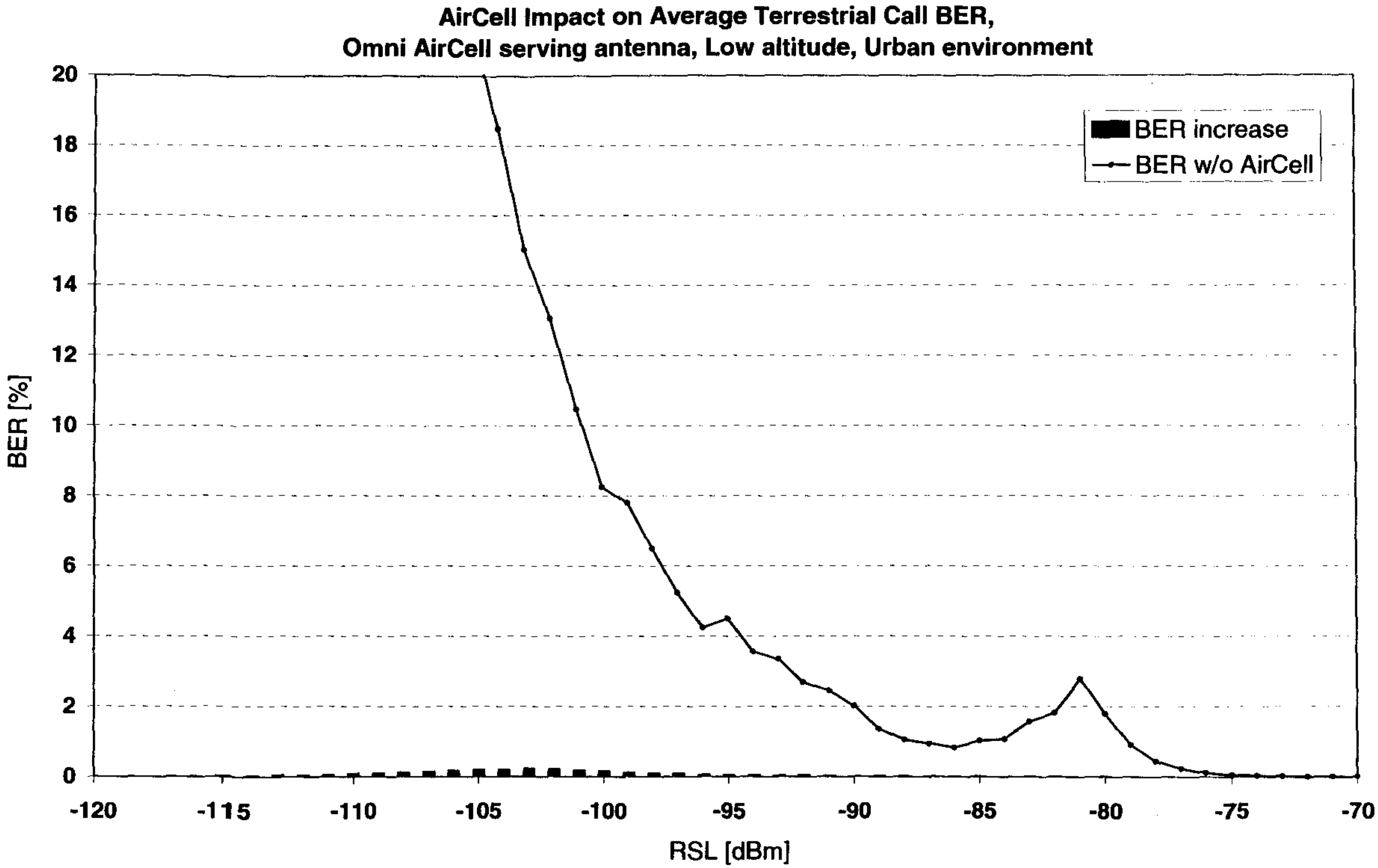

Figure 5.10 BER and AirCell impact, Urban environment, Low altitude, Omni AirCell server

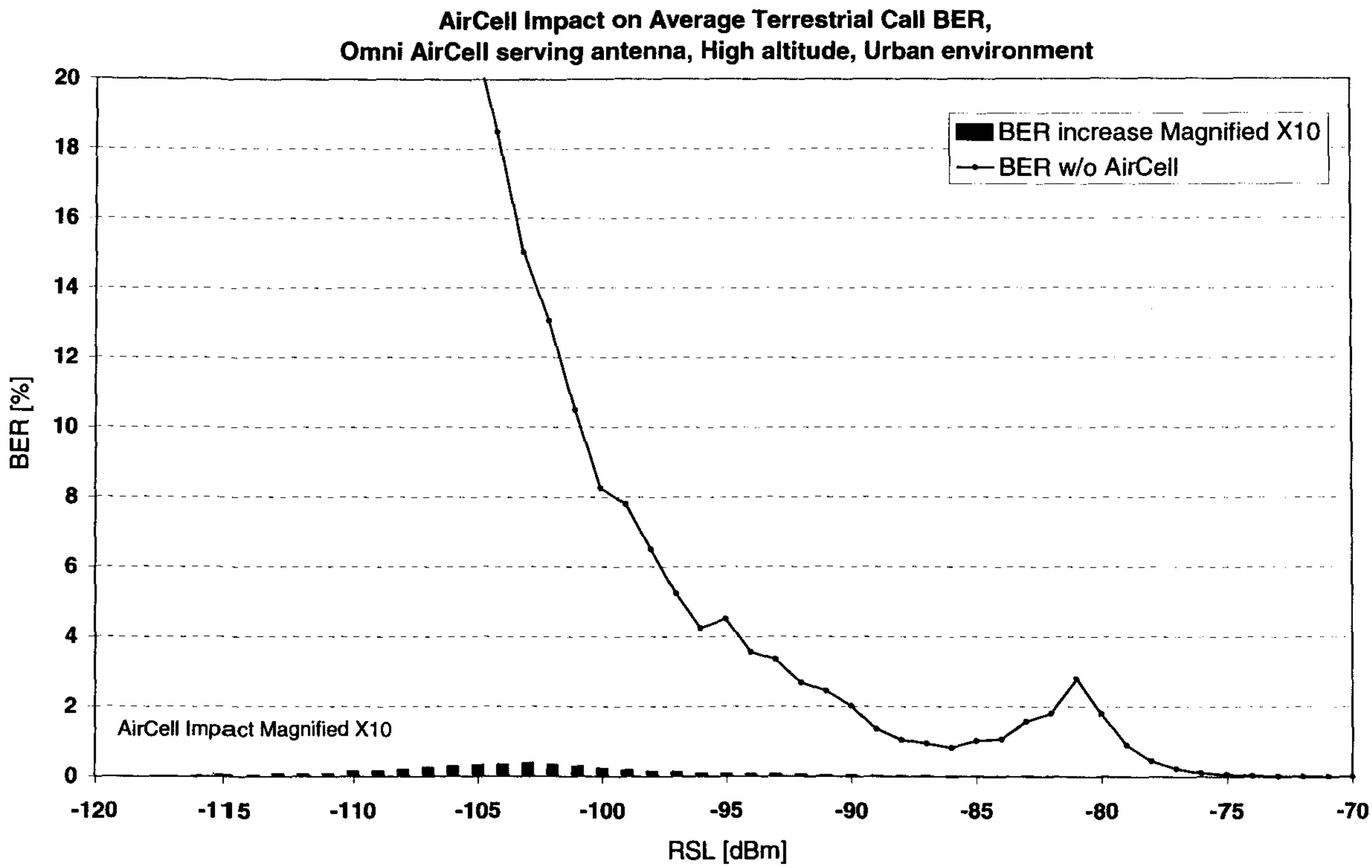

Figure 5.11 BER and AirCell impact, Urban environment, High altitude, Omni AirCell server

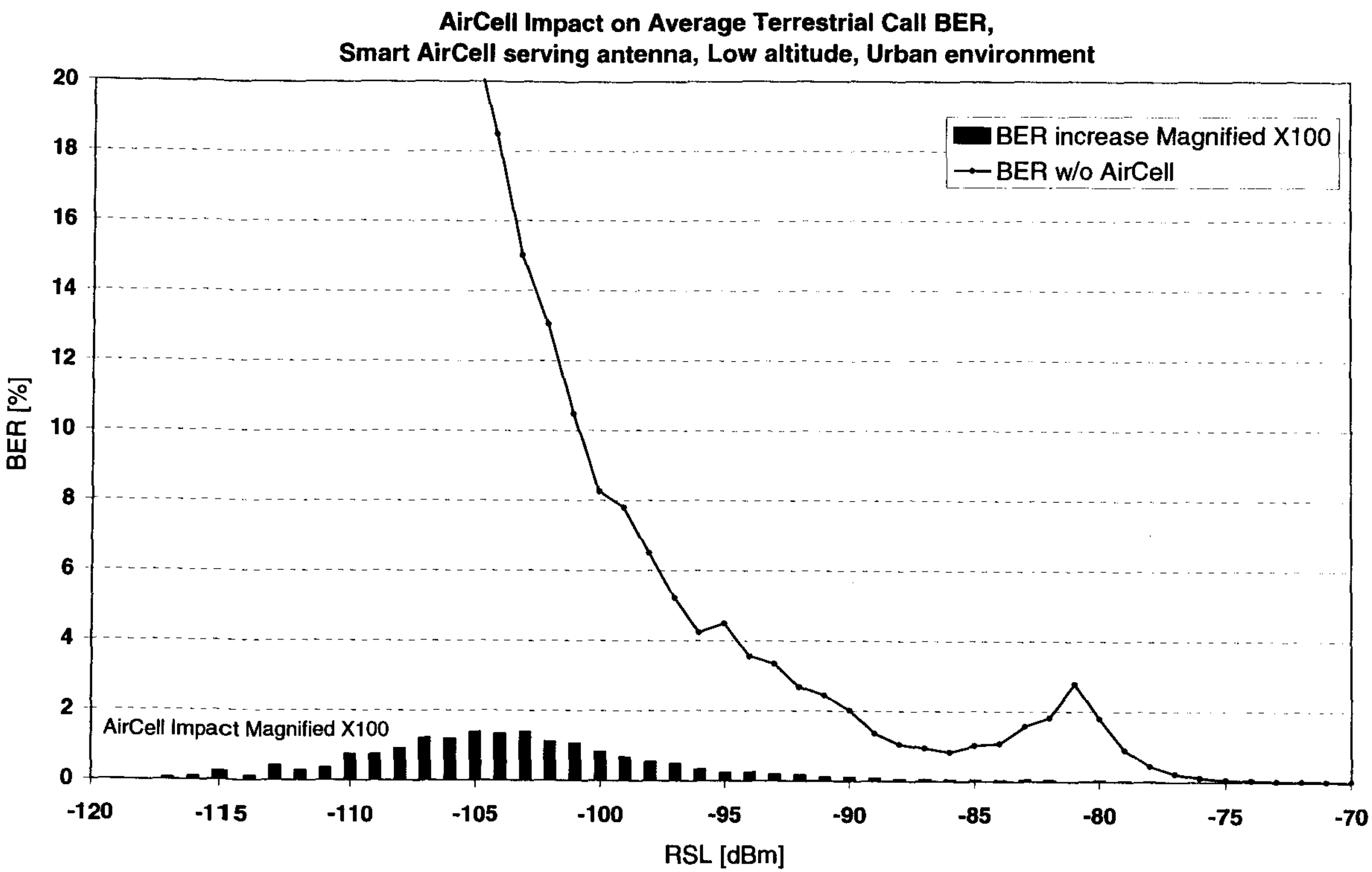

Figure 5.12 BER and AirCell impact, Urban environment, Low altitude, Smart AirCell server

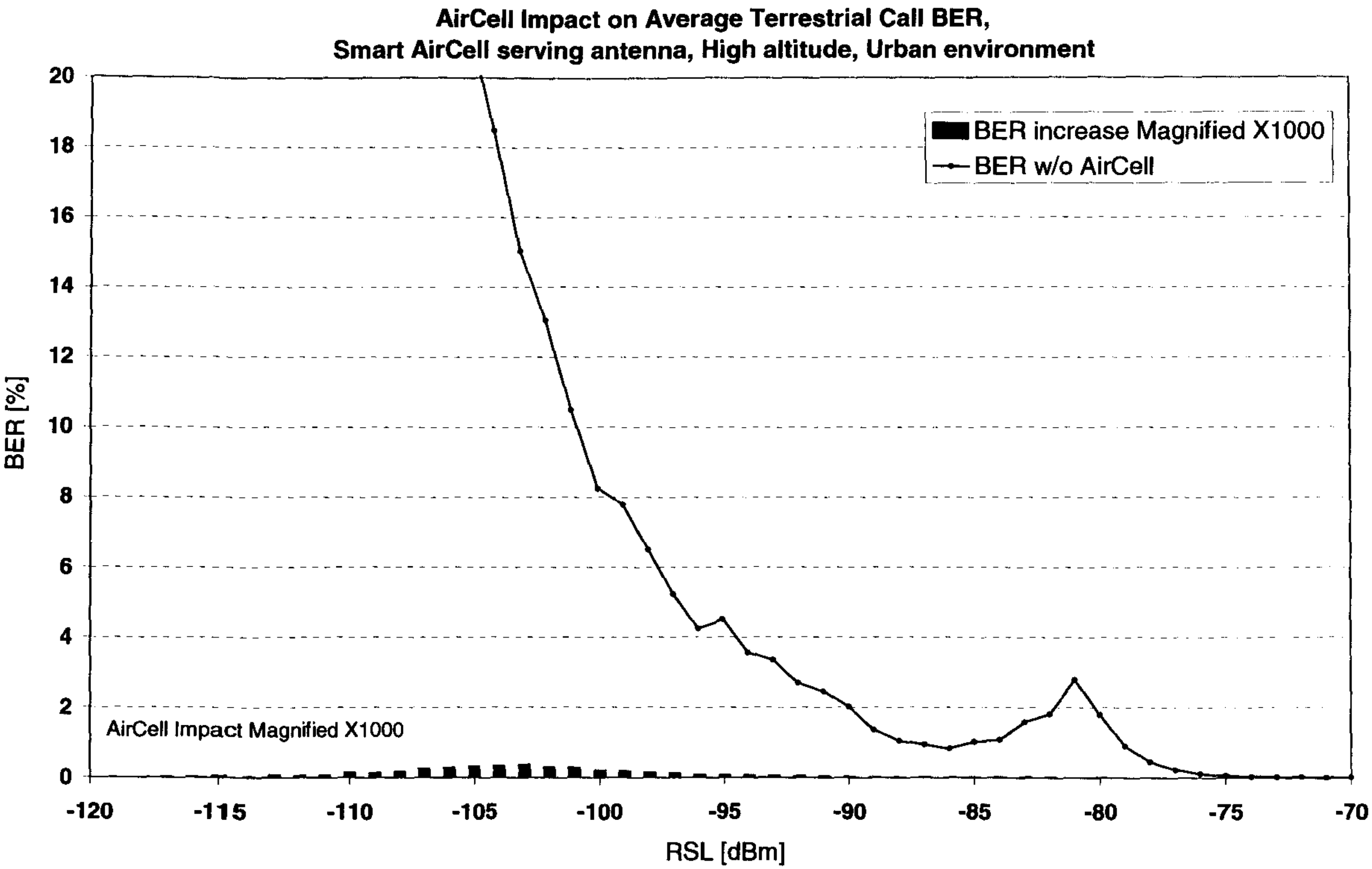

Figure 5.13 BER and AirCell impact, Urban environment, High altitude, Smart AirCell server

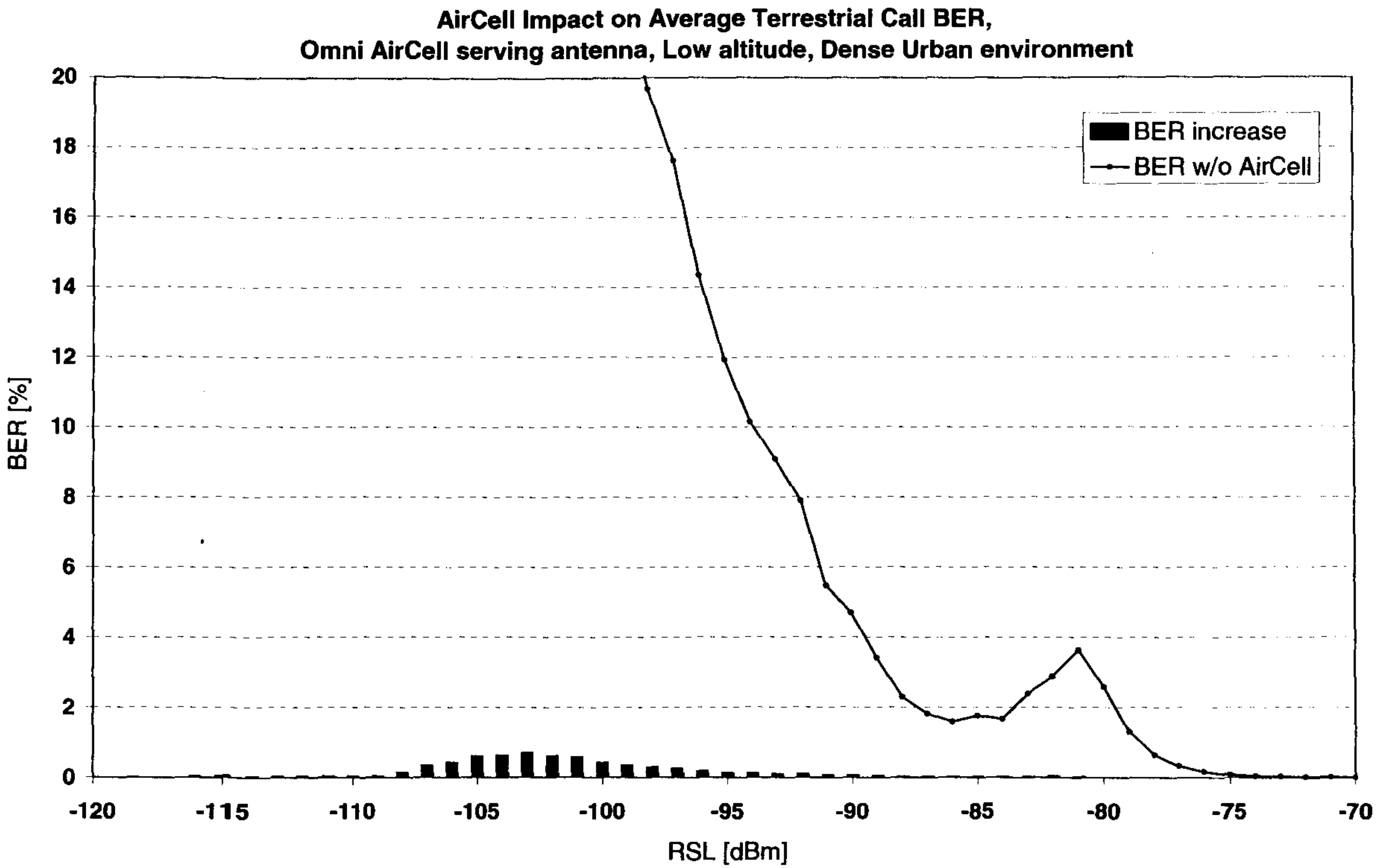

Figure 5.14 BER and AirCell impact, Dense Urban environment, Low altitude, Omni AirCell server

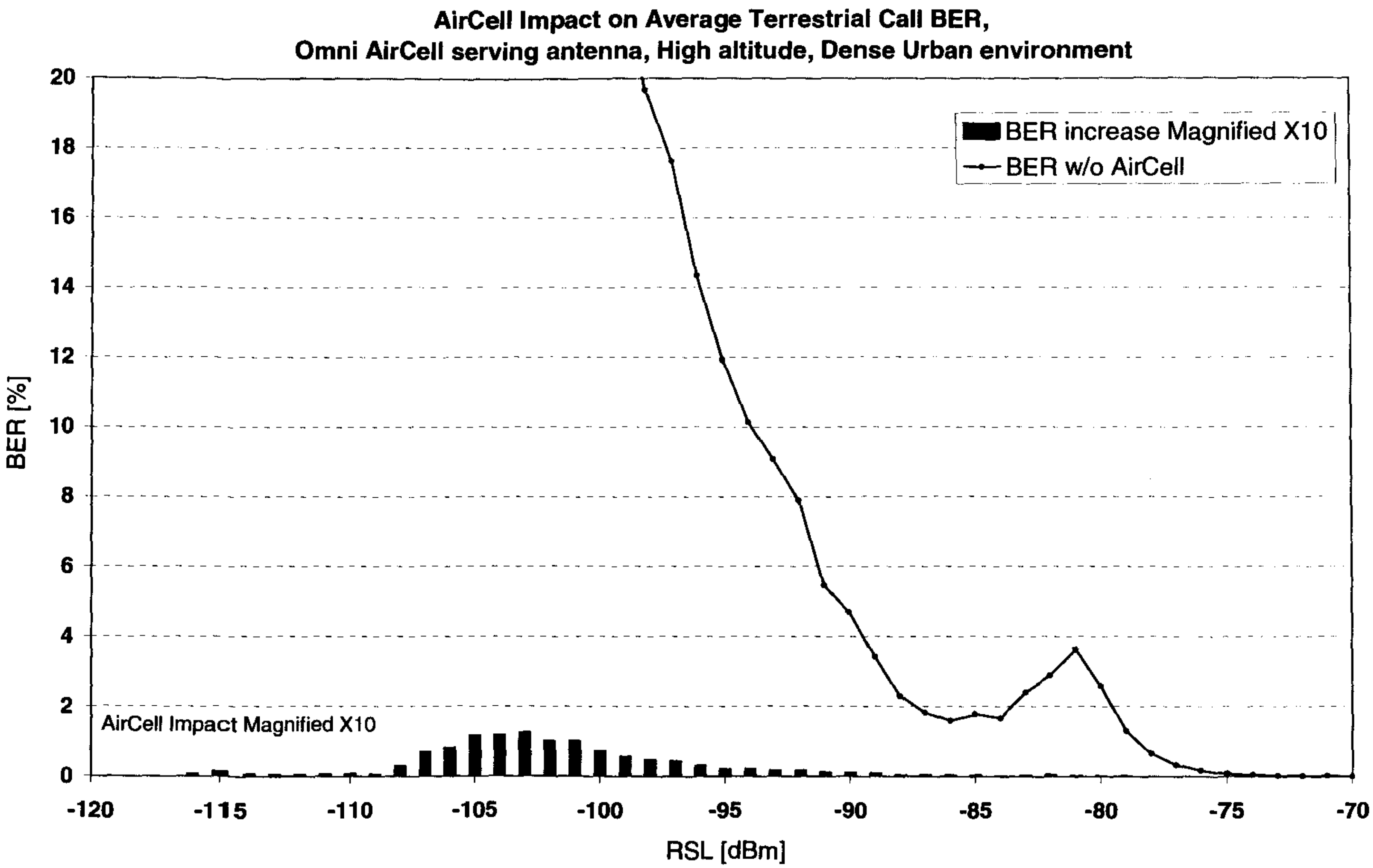

Figure 5.15 BER and AirCell impact, Dense Urban environment, High altitude, Omni AirCell server

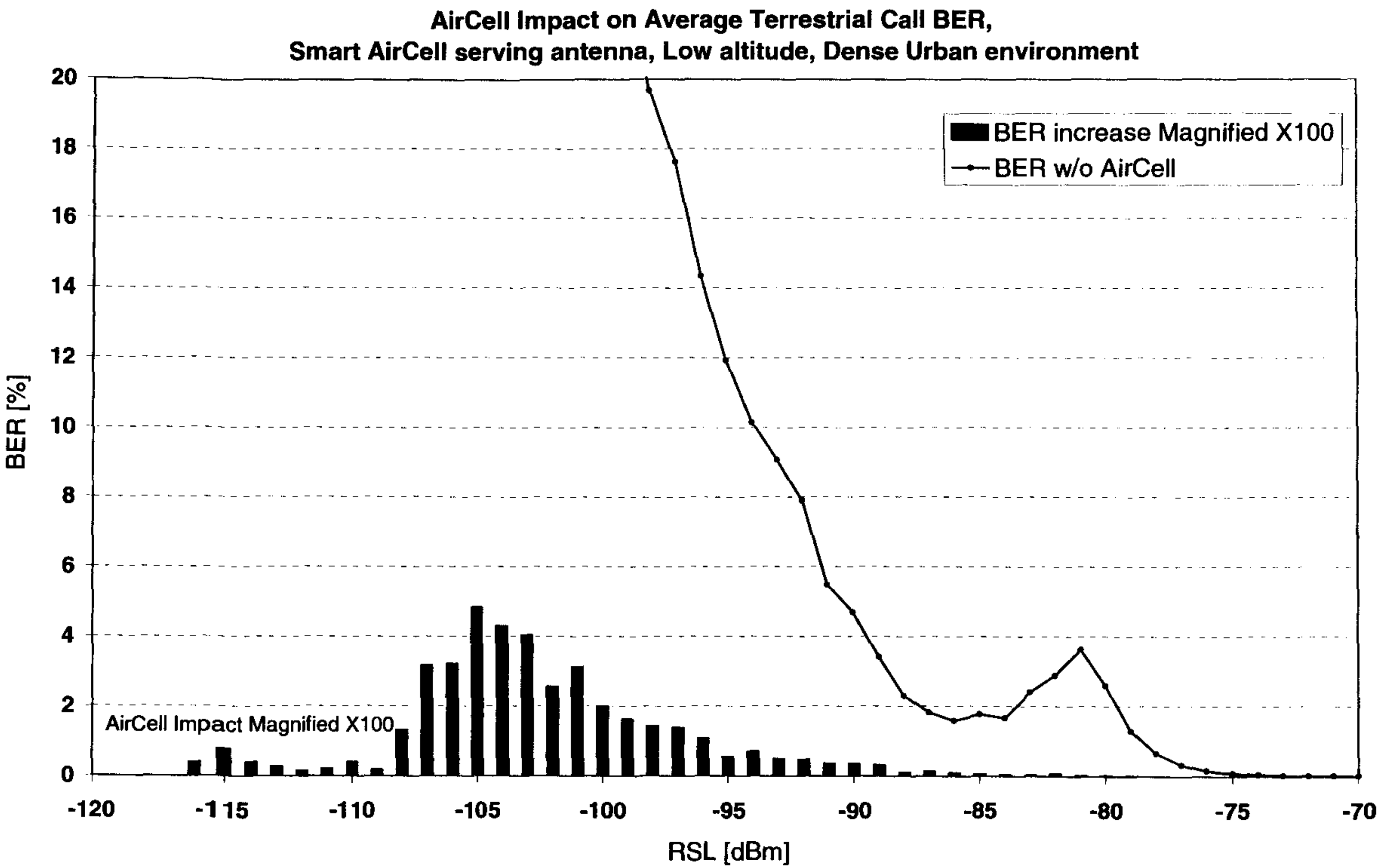

Figure 5.16 BER and AirCell impact, Dense Urban environment, Low altitude, Smart AirCell server

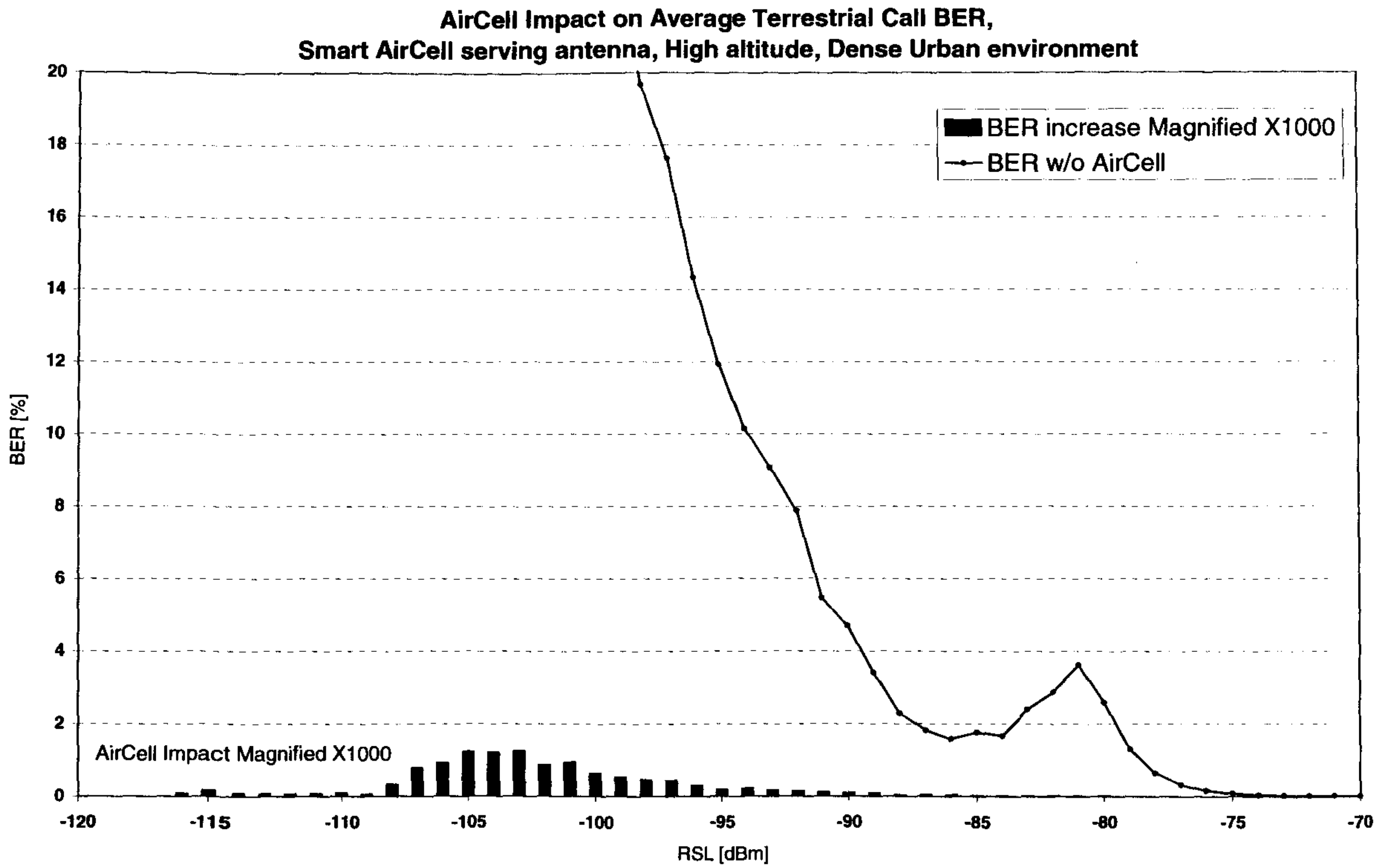

Figure 5.17 BER and AirCell impact, Dense Urban environment, High altitude, Smart AirCell server

As one would expect, the worst case among Figure 5.2 through Figure 5.17 is the case in which an aircraft passes at low altitude near a rural site (Figure 5.2). As aircraft altitude increases, the apparent elevation above the horizon increases (placing the AirCell signal further into the less sensitive antenna pattern sidelobes) and/or slant range to the terrestrial observer site increases (increasing free space losses). The observed AirCell signal level is also reduced with the use of a 'smart antenna' system at the AirCell serving site. In these cases, the AirCell contribution to terrestrial bit error rate decreases dramatically. The AirCell impact also decreases as ambient noise increases. Some of the plots above required 'magnification' of the AirCell BER impact by a factor of 10, 100, or 1000 to make the impact visible at all.

These results are logical, as the rural environment has the lowest noise floor, and low level AirCell signals are more evident than they are when compared to the higher noise floors present in the Suburban, Urban, or Dense Urban cases. Also in rural areas, coverage is often weak, and path losses sometimes exceed acceptable link budgets. In such an environment, the least amount of interference is required to degrade call quality. Referring to the 1997 test data, we see that the high altitude data showed lower AirCell signal levels, as did the smart antenna cases. Thus, the low altitude, omni AirCell serving site, rural environment case constitutes the worst case from an interference perspective.

Examining this case (see Figure 5.2), at an average call RSSI of –104 dBm, the IS-136 reverse link reaches 2.3% BER without an AirCell influence. The AirCell impact is 0.3% at this point, which would result in a 2.6% BER *for the duration of an aircraft flyby.* (Note that this result is a signal-to-signal comparison only at this point, and the probability of an AirCell subscriber being nearby, transmitting cochannel, etc. is not considered.) While both values are beyond the 2% BER design goal, they are less than the 3% that EIA standards imply to be adequate, and fall in the 'acceptable' quality range. As the signal passes through –110 dBm, the BER climbs to 6.2%, plus an AirCell impact of 1%. The curve is very steep here, and performance with an AirCell signal is equivalent to about a ½ dB weaker signal without an AirCell presence. Either way, voice quality is marginal.

Likewise, as the received signal level passes through –111 dBm, BER is 8.3%, to which AirCell may add 1.4%...Not quite 10% total. At –112 dBm, BER is 10.3%, to which AirCell may add 1.4% additional BER for the duration of a flyby at low altitude in a rural area. In both cases, the impact is roughly equivalent to a ½ dB lower signal level without AirCell present. It's *extremely* unlikely that a terrestrial subscriber would be able to perceive an impact of this magnitude.

There is an interesting anomaly in the data, which is common to all plots. This occurs at about –81 dBm. It would appear that some calls operating near this *average* received power encountered significant fades, which raised the average bit error rate for the call. This may also have been related to system call handling, as this level falls <u>just below</u> the bottom of the DPC 'power box', at which the site should ask the mobile to step up power. One possible explanation is that a few calls falling near this average level experienced deep fades which dynamic power control could not compensate for (producing very large BER spikes), but that the fades were short enough in duration that the overall average RSL only changed a couple of dB. The data has not been searched to isolate and analyze this anomaly to date, as it is not a major issue in terms of TDMA susceptibility to AMPS interference. If otherwise strong calls experience moments of deep fading and high BER, they are only vulnerable to low level interference sources at times when the BER is already unacceptably high from the fade itself.

Restating the basic question: Does the AirCell signal, considered as an interferer, take TDMA calls 'over the edge' from good call quality to a lesser call quality? Looking at whole dB steps, the answer is no. Most cases require magnification for the AirCell impact to be visible in the plot.

Looking at the intermediate product from 'step 4' above, one can gain some insight into these amplitude/BER thresholds... This step provides BER for a constant-power TDMA signal in the presence of interference having statistics drawn from the 1997 flight test. It provides a simpler case than that above in which time domain caller statistics interact with the flight test statistics.

'Step 4' data conveys less information regarding total AirCell BER impact, but it does provide insight into potential AirCell influence on TDMA system RSL requirements.

Looking first at the Rural, Omni AirCell server, Low altitude aircraft case, for a specific (constant) reverse channel received signal level, the step 4 output can be compared to the no-interferer case (shown in the leftmost, yellow-highlighted column of Table 5.8). The resulting Table 5.9 has three columns, showing RSL vs. BER both with an AirCell influence (using the 1997 flight test data signal strength distribution) and with no AMPS influence:

Table 5.9 BER for constant TDMA signal level, Rural, Low altitude, Omni server.

RSL [dBm]	With AirCell BER [%]	No Interferer BER [%]
-100	0.00	0.00
-101	0.00	0.00
-102	0.01	0.00
-103	0.03	0.00
-104	0.05	0.00
-105	0.15	0.02
-106	0.32	0.09
-107	0.57	0.23
-108	1.21	0.71
-109	2.31	1.65
-110	4.24	3.21
-111	*6.78*	*5.4*
-112	10.00	8.16
-113	*14.39*	*11.62*
-114	21.64	19.7
-115	23.91	20.83
-116	26.32	23.56
-117	29.14	26.65
-118	33.74	31.88
-119	34.32	32.44
-120	37.44	35.93

Consider BER thresholds greater than 2%, and in the nonlinear portion of the BER curve. Above 5% BER and above 10%BER, these values are achieved at a received signal level of –111 dBm and –113 dBm, respectively. The target values are exceeded in the same step, whether or not AirCell interference is present. *The AirCell influence is less than the 1 dB resolution for RSL impact in this figure.*

Based on the interpolated data, the AirCell presence does have a mathematically *resolvable* influence in the low altitude, omni server, rural case. The 5% BER threshold is crossed approximately 0.5 dB sooner with an interferer present, and the 10% threshold is crossed about 0.6 dB sooner with an interferer present. Notably, at these levels a TDMA call is already significantly degraded, and an impact equivalent to a 1/2 dB change in path loss isn't significant against the background of the terrestrial fading environment.

In a laboratory environment, 1/2 dB can sometimes be *resolved,* though the absolute *accuracy* of measurements (with conventional test equipment) is usually poorer. In an actual field experiment, carried out in a fading environment, it is highly questionable that an influence of this magnitude could be observed at all, even with the best available test equipment.
It is unlikely in the extreme that human listeners could subjectively detect such an impact...
...which is only present on the same voice channel used by an aircraft while the aircraft has a call up, and is within a few miles of the observer site. Compounding these probabilities with a 1/2 dB impact, there appears to be no logical argument that terrestrial callers can subjectively observe *any* impact from AirCell operation.

Again, this result relates to Rural, Low altitude, omni AirCell server... the worst case for potential impact. What about the remaining 15 cases discussed?
The 1 dB resolution tables are presented below in Table 5.10 through Table 5.25:

Please note: Table 5.10 *through* Table 5.25 *represent the* *<u>static</u>* *(non-fading) TDMA signal level case, and do not take into account the TDMA subscriber signal statistics which were included in* Figure 5.2 *through* Figure 5.17.

Table 5.10 BER for constant TDMA signal level, Rural, Low altitude, Omni server, 0.1 dB res.

RSL [dBm]	With AirCell BER [%]	No Interferer BER [%]
-112.9	13.76	10.99
-112.8	13.19	10.46
-112.7	12.67	***10.01***
-112.6	12.21	9.64
-112.5	11.78	9.32
-112.4	11.39	9.05
-112.3	11.02	8.81
-112.2	10.67	8.59
-112.1	***10.33***	8.38
-112.0	10.00	8.16
-111.9	9.67	7.92
-111.8	9.34	7.67
-111.7	9.00	7.40
-111.6	8.67	7.12
-111.5	8.34	6.83
-111.4	8.02	6.54
-111.3	7.70	6.25
-111.2	7.38	5.96
-111.1	7.08	5.67
-111.0	6.78	5.40
-110.9	6.49	***5.14***
-110.8	6.21	4.89
-110.7	5.94	4.65
-110.6	5.68	4.42
-110.5	5.43	4.20
-110.4	***5.18***	3.99
-110.3	4.94	3.78
-110.2	4.70	3.59
-110.1	4.47	3.40
-110.0	4.24	3.21
-109.9	4.02	3.03
-109.8	3.80	2.85
-109.7	3.59	2.68
-109.6	3.38	2.52
-109.5	3.19	2.36
-109.4	2.99	2.20
-109.3	2.81	2.05
-109.2	2.63	1.91
-109.1	2.47	1.78
-109.0	2.31	1.65
-108.9	2.17	1.53
-108.8	2.03	1.41
-108.7	1.90	1.31
-108.6	1.78	1.21
-108.5	1.67	1.11

Table 5.11 BER for constant TDMA signal level, Rural, High altitude, Omni server.

RSL [dBm]	With AirCell BER [%]	No Interferer BER [%]
-102	0.00	0.00
-103	0.00	0.00
-104	0.00	0.00
-105	0.02	0.02
-106	0.10	0.09
-107	0.26	0.23
-108	0.76	0.71
-109	1.73	1.65
-110	3.34	3.21
-111	*5.61*	*5.40*
-112	8.43	8.16
-113	*12.05*	*11.62*
-114	19.96	19.70
-115	21.36	20.83
-116	24.02	23.56
-117	27.08	26.65
-118	32.18	31.88
-119	32.77	32.44
-120	36.19	35.93

Table 5.12 BER for constant TDMA signal level, Rural, Low altitude, Smart server.

RSL [dBm]	With AirCell BER [%]	No Interferer BER [%]
-102	0.00	0.00
-103	0.00	0.00
-104	0.00	0.00
-105	0.02	0.02
-106	0.09	0.09
-107	0.24	0.23
-108	0.72	0.71
-109	1.67	1.65
-110	3.25	3.21
-111	*5.49*	*5.40*
-112	8.25	8.16
-113	*11.70*	*11.62*
-114	19.69	19.70
-115	20.96	20.83
-116	23.66	23.56
-117	26.76	26.65
-118	31.94	31.88
-119	32.53	32.44
-120	36.00	35.93